



## **Editorial: Seasonal-to-decadal prediction of marine ecosystems: Opportunities, approaches, and applications**

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# Editorial: Seasonal-to-Decadal Prediction of Marine Ecosystems: Opportunities, Approaches, and Applications

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## Editorial on the Research Topic

### Seasonal-to-Decadal Prediction of Marine Ecosystems: Opportunities, Approaches, and Applications

A quiet revolution is taking place in marine science. Like a caterpillar entering its chrysalis, marine biology is metamorphosing into something new. Leaving its empirical origins behind, the first signs of the predictive skill that characterizes sciences such as physics and chemistry are now also emerging in biology. Climate scientists and oceanographers, taking advantage of the tremendous advances in observational technology, scientific understanding, and computing power in recent years, can now make skilful forecasts of the state of the ocean seasons, years, and in some cases up to a decade into the future (Doblas-Reyes et al., 2013; Meehl et al., 2014). Such forecasts are an exciting opportunity for marine ecologists and fisheries scientists, who finally may be able to realize the dream of predictive skill present at the very birth of their field (e.g., Helland-Hansen and Nansen, 1909). The first such pioneering products have already been operational for some years now (e.g., Hobday et al., 2011; Eveson et al., 2015), and a second wave of products, inspired by the successes of the first, is now building. A revolution is indeed, underway.

The manuscripts collated here sample the state-of-the art in seasonal-to-decadal forecasting of marine ecosystems. Starting with the ocean itself, we look at developments in forecasting the physical and biogeochemical environment. Case studies examine both operational marine ecological forecast products and other instances where products could be developed. We then look more generally at the way that forecasts can be used and evaluated and at their relationship to climate-scale projections. Finally, we synthesize the lessons learned from this first generation of forecasts.

Ocean predictability forms the basis for ecological predictability, and advances in this field are providing exciting new opportunities to develop ecological forecasts from seasonal to multi-annual to even decadal scales. For example, while the open ocean has been the main focus of forecast development, economically important coastal regions have received less attention. Tommasi et al. assess the ability of an earth system model to make predictions of such regions on the multi-annual timescale. They find surprisingly good results, showing useful skill for most regions, allowing potential development of forecasts directly relevant to fisheries, aquaculture, and coastal assets such as coral reefs. Rousseaux et al. highlight another new front by demonstrating the ability of a fully-coupled biogeochemical model to forecast chlorophyll. They suggest that it may be possible to move beyond temperature-driven ecological forecasts and potentially incorporate other biologically relevant variables, such as productivity.

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We present several case studies of systems where there are already operational forecast products, or where they could be developed in the future. NOAA's Monthly Bleaching Outlook, detailed by Liu et al. is one of the longest running high profile marine ecological forecast products. This system was key in foreseeing and responding to the third global bleaching event (2014–2016), where it motivated adaptation responses (e.g., closing reefs to tourism) even before the event started. Mills et al. describe the development of a forecast system for the timing of American lobster landings in the Gulf of Maine, inspired by the needs of the local fishing industry. The work serves as an excellent example of the full development cycle of a forecast product, starting from end-user needs, applying science, and communicating the results in an easily understood manner. Hátún et al. proposes a causal link between the breeding success of kittiwakes on the Faroe Islands and the abundance of zooplankton on the feeding grounds that can potentially drive a predictive system. Strand et al. present an investigation of the advection of cod larvae along the Norwegian coast, showing that wind driven events can hinder larvae reaching their nursery grounds and potentially inform a recruitment forecast.

The ultimate test of model performance comes when it is applied in the real world. Turner et al. test a bycatch forecast model using a designed experiment with commercial fishing vessels but find that, in the real world, their model has little predictive skill. While this may be disappointing, there have nevertheless been clear benefits arising from close collaborative research with the industry.

Seasonal and decadal forecasting systems are also intimately linked to climate projection systems: indeed, in most cases they are actually the same model being used in slightly different ways. Hobday et al. show how to combine predictions and projections to develop a full picture of the evolution of the ocean system. Their framework can be used by marine managers and businesses to improve their decision making and profitability, but also to prepare coping strategies during adverse times. Silber et al. also examine this relationship via a discussion about the challenges of modeling marine mammal distributions in a changing climate. The authors provide a useful scheme for prioritizing the organisms to focus on, with the best candidates being vulnerable species where there is a high management need and plentiful data.

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The final paper, Payne et al. reviews the current state of marine ecological forecasting, with a view to summarizing the lessons learned. They find that the majority of operational marine ecological forecast products are of species' spatial distributions, rather than their abundance. As abundance prediction is critical for fisheries management and quota setting, improving ecological abundance forecasts will expand the set of users. The lesson common to all of the forecast products they examine is the importance of a close collaboration between scientists, who can inform about what is feasible, and end-users, who can define what is useful.

In conclusion, the papers here show that marine ecological forecasting is a rapidly evolving field with great potential to support the decision-making of end-users. However, what ultimately emerges from the chrysalis remains to be seen. Will the field break into the scientific and management mainstream, or will it remain limited to niche applications? Will multi-year forecasting be possible in all regions of the world's ocean? Maintaining the existing momentum and increasing the portfolio of ecological forecast products will be challenging, particularly once the “low-hanging fruit” have all been “picked.” Nevertheless, based on the products available to-date, it is clear that seasonal-to-decadal prediction of marine ecosystems is both a viable scientific discipline and one that will make a significant contribution to the management and performance of marine industries now and in the years to come.

## AUTHOR CONTRIBUTIONS

MP prepared a first draft of the manuscript. All authors contributed to further editing and refinements. All authors have approved the final version of the manuscript.

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